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Angivelse av tegningsfigur som ønskes publisert sammen med sammendraget	Fig. nr. 6

A NEW WATER-IN-OIL MONITOR BASED ON HIGH FREQUENCY MAGNETIC FIELD EXCITATION

The present invention relates to a method and an arrangement for determining water content in flows, in particular in mixtures of oil, HC-gases and water, in a fluid transporting body method.

INTRODUCTION

The water fraction meters used in the oil process industry to day will all be influenced by the gas content in the oil/water/gas-mixture and different kind of iterative algorithms are used to compensate for this error. Micro wave meters are dependent on the salinity of the water component in both oil and water continuous phases and capacitance meters must be equipped with a conductivity meter to cover the whole range of water fraction from 0 to 100%.

The water fraction meter described in this paper can detect the water fraction in tree phase flows on line independent of the gas content in the mixture. To day the conductivity of the water component is determined off line

by laboratory tests of processed water. The described instrument can monitor the water conductivity on line.
MEASUREMENT PRINCIPLE

A sketch of the meter spool pipe principle is shown in the enclosed Figure 1. There is shown an electrical insulated liner around which there is exitation and detections coils. The coils are protected by a screen.

The coil can be regarded as a parallel coupling between an inductance, a capacitance and a resistance. The capacitance consists of different spread capacitances between the coil windings and an equivalent parallel resistance made up by the resistance in the coil windings and the power loss in the volume of the mixture flowing through the coil. The first one is constant but the second one is dependent on the amount of water in the mixture. The coil is part of a feedback circuit witch latch the excitation frequency to the coil's resonance frequency. The current in the feedback loop will then be dependent on the induced power loss in the mixture. The resonance frequency can be determined by the number of windings in the coil and the optimal frequency range will be dependent on the current penetration depth and the induced power loss in the mixture. The higher the frequency the higher is the loss and thus the higher is the sensitivity of the meter, but the frequency is limited by the current penetration depth of the induced current in both the mixture and the coil windings.

In oil/gas continuous mixtures the water consists as insulated droplets in the oil/gas. The induced loss in these distributed droplets is small compared to the loss in water continuous mixtures (this is the reason for making the power transformer cores of thin insulated steel plates). However, the penetration depth of the eddy currents is large so we can use higher resonance frequency and thus increase the sensitivity.

Due to this fact we are using two coils in our meter simultaneously optimised for oil/gas continuous mixtures and water continuous mixtures respectively.

The induced loss will be dependent on the conductivity in the water component. By using two different coils with different resonance frequencies it is possible to compensate for variation in the conductivity and hence the conductivity of the water can be determined as well.

To keep the coil resistance constant it is important to avoid the frequency dependent resistance in the coil windings do to the electrical penetration depth. This can be avoided by winding the coil with a cable of separately insulated Cu-lices with a radius less than the electrical skin depth of Cu. In our experiment we have used flat Cu-cords at a thickness of 40 μm.

THEORY

The eddy current loss in an infinitely large plate with thickness d and electrical conductivity s, penetrated by a magnetic field B parallel the plate at a frequency w, is:

$$P_0 = \frac{\sigma\omega^2 d^2 B^2}{12} \qquad (1)$$

where B is the rms-value of the penetrating magnetic field, s the conductivity of the medium and w the frequency of the magnetic field. The resonance frequency for the different coils lays in the region of 2 to 8 MHz and the electrical conductivity in processed water from the North Sea oil is 4-6 S/m.

The skin depth for the electrical current induced in a conducting medium is:

$$\delta = \sqrt{\frac{2}{\mu_0 \mu_r \omega \sigma}} \qquad (2)$$

where m_0 and m_r are the magnetic permeability for the empty space and the relative permeability respectively.

At a frequency of 5.5 MHz which is used for the most sensitive coil for water continuous mixtures the

penetration depth for the eddy currents will approximately be 10 cm. This is acceptable for production pipes up to a diameter of 20 cm (8")

The skin depth in µm of the Cu lead in the coil as a function of frequency (Mhz) is shown in the following Fig.2.

EXPERIMENTAL RESULTS

Fig.3. shows the result from a 9-turn coil which is sensitive for the water content in the mixture over the whole range. The impedance kΩ is shown as a function of the water fraction β.

Fig.4. shows a coil which has increased sensitivity for oil/gas continuous mixtures

Fig.5. gives the result from a coil configuration that has an increased sensitivity for water continuous mixtures. By combining those two last coils in a meter, an increased sensitivity can be obtained both in water discontinuous mixtures and water continuous mixtures.

Fig.3. Nine layer 9 windings of flat Cu-cord (15 x 0.04 mm). f = 5.5 MHZ

Fig.4. One layer, 15 windings of flat Cu-cord, f = 2 MHz

Fig.5. 4 layer, 4 winding coil of flat Cu-cord. f = 9 kHz.

THE PRINCIPLE USED IN PROCESS TOMOGRAPHY

When the different phases in the crude are separated, i.e. not homogeneous mixed, the water content can not be measured with the same accuracy as for homogeneous mixtures if the principle explained above is used.
The arrangement for utilising this induction principle in a tomographic arrangement is shown in Fig.6.

Fig.6. is aroposed coil arrangement for tomographic detection of multiphase flow.
The figures shows a pipe section. To the outside surface of the pipe, a number of coils are mounted close contacting

the pipe surface. The three phases gas, oil and water are shown in the pipe section. The water amount may be measured by means of the arrangement.

Here we can determine the power loss generated in the alternating magnetic field from one coil at the time. Based on mathematical models of the magnetic field from the coils it is possible to work out a reconstruction algorithm imaging the water distribution in the meter cross section. It may also be possible to excite one of the coils at a time and use all the other coils as pick up coils and detect the attenuation of the magnetic field from the transmitter to the receiver coils and thus reconstruct a picture of the area of low field penetration which must be areas of water.

I den nye er en annen elektronikk benyttet. Her benyttes en resonanskrets der resonansfrekvensen endres med endringer i vanninnhold og salinitet. Også impedansen ved resonans endres ved disse endringene. Ved bruk av resonanskrets, er frekvensen alltid "låst" i resonansfrekvens, der følsomheten for endringer vil være størst. En sparer da en spole, slik at den nye løsningen blir billigere og enklere.

I en olje-vann blanding kan strømningen deles inn i oljekontinuerlige strømninger for lave vannfraksjoner og vann-kontinuerlig for lave oljefraksjoner. Som det kan sees ut fra plottet der impedansen er plottet som funksjon av vannfraksjonen, ser man en diskontinuitet i kurven. I dette punktet går strømningen fra å være olje-kontinuerlig til vann-kontinuerlig eller omvendt.

Målinger har vist at følsomheten i de to regionene er avhengig av antall viklinger og om spolen vikles med ordinær kobbertråd eller et kobberbånd.

Dette gir en fleksibiltet der følsomheten kan optimaliseres for en gitt applikasjon. For eksempel, ønsker man kanskje en maksimal følsomhet for små vannfraksjoner i olje. I en annen applikasjon ønsker man kanskje maksimal følsomhet for små andeler olje i vann. Dette krever to forskjellige spoler, og en maksimal følsomhet over hele

måleområdet får vi om to spoler kombineres. En annen fordel med det, er at endringer i saliniteten kan det da kompenseres for.

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The Clarendon Press, Oxford, Vol. 1, 1st edition 1873.

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[5] A J Peyton, M S Beck, A R Borges, J E de Oliveira, G M Lyon, Z Z Yu, M W Brown, J Ferrerra, *Development of Electromagnetic Tomography (EMT) for Industrial Applications. Part 1: Sensor Design and Instrumentation*

Proceeding of 1st World Congress on Industrial Process Tomography, Buxton, Greater Manchester, April 14-17, 1999, 306.

PATENT CLAIMS

1. Method for determining water content in flows, in particular in mixtures of oil, HC-gases and water, in a fluid transporting body, characterized in on line measuring the water fraction in three phase flows by using a coil optimised for oil/gas-continous mixtures, and a coil optimised for water-continous mixtures, respectively.

2. Method according to claim 1, characterized in measuring the induced loss hich is dependent on the the water content conductivity.

3. Method according to claim 1-2, characterized in the two coils operating at two different frequencies in order o compensate for variation in the water conductivity, hence determining said water conductivity.

4. Method according to claim 1-3, characterized in using a coil winding which arranged of a cable of separately insulated conductive wire or cords.

5. Method according to claim 1-4, characterized in using wire or cords includes Cu-lices having a radius less than the electrical skin depth of Cu (copper).

6. Method according to any of preceding claims, characterized in using flat Cu-cords at a thickness of 40 µm.

7. Method according to any of preceding claims, characterized in using a resonance frequensy in the range of 2 to 8 MHz.

8. Method according to any of preceding claims, characterized in using a resonance frequensy of 5,5 Mhz in order to obtaining a penetration depth of about 10 cm.

9. Method according to any of preceding claims, characterized in using a multi turn coil, e.g. a 9-turn coil, which is sensitive for water content in the mixture over the whole range.

10. Method according to any of preceding claims, characterized in using a number of coils arranged to the outside surface of the fluid transporting body, such as pipe, the coils being arranged to be driven to reconance frequency.

11. Method according to any of preceding claims, characterized in determining the power loss generated in the alternating magnetic field from one coil at the time.

12. Method according to any of preceding claims, characterized in working out a reconstruction algorithm imaging the water distribution in the meter cross section based on mathematical models of the magnetic field from the coils.

13. Method according to any of preceding claims, characterized in exciting one of the coils at a time and use all the other coils as pick up coils and detect the attenuation of the magnetic field from the transmitter to the receiver coils and thus reconstruct a picture of the area of low field penetration being areas of water.

14. Arrangement of determining water content in multi phase flows in a fluid transporting body, characterized by a coil optimised for oil/gas-continous mixtures, and a coil optimised for water-continous mixtures, respectively.

15. Arrangement according to claim 14, characterized by a number of coils arranged to the outside surface of the fluid transporting body (such as a pipe), the coils being arranged to be driven to reconance frequency.

16. Arrangement according to claim 14, characterized by a multi turn coil, e.g. a 9-turn coil, which is sensitive for water content in the mixture over the whole range.

17. Arrangement according to any of preceding claims, characterized by a number of coils arranged to the outside surface of the fluid transporting body, such as pipe, the coils being arranged to be driven to reconance frequency.

18. Arrangement according to any of preceding claims, characterized in determining the power loss generated in the alternating magnetic field from one coil at the time.

19. Arrangement according to any of preceding claims, characterized by a reconstruction algorithm imaging the water distribution in the meter cross section based on mathematical models of the magnetic field from the coils.

20. Arrangement according to any of preceding claims, characterized in being enabled to exciting one of the coils at a time and use all the other coils as pick up coils and detect the attenuation of the magnetic field from the transmitter to the receiver coils and thus reconstruct a picture of the area of low field penetration being areas of water.

Abstract:

This new measurement system is based on measuring the induced loss (eddy currents) in conductive components in the oil. In North Sea crudes the water in the oil is conductive. Therefore this principle can be used to measure the water fraction in crude oil both in oil-continuous and water-continuous mixtures. The total induced loss in the measurement volume will be dependent on the amount of water in the oil. This electrical loss will occur as a parallel resistance in the coil impedance and since the excitation coil is kept at resonance this loss can be determined by measuring the total coil resistance. If the mixture is homogeneous one coil around the pipe is sufficient. In inhomogeneous flows as in downhole situations a number of coils around the pipe can be used making a tomographic system. The method is robust and cheep and will probably make the next generation of water monitors in multiphase meters for the oil industry and since the sensors selectively measure the water volume in the pipe and will not be influenced by the ratio between gas and oil they will increase the reliability in multiphase meters as well. The measurement principle is proposed to be used in process tomographs. This is important when separated phases occur down hole in radiating production pipes where stratified flow regimes will occur.

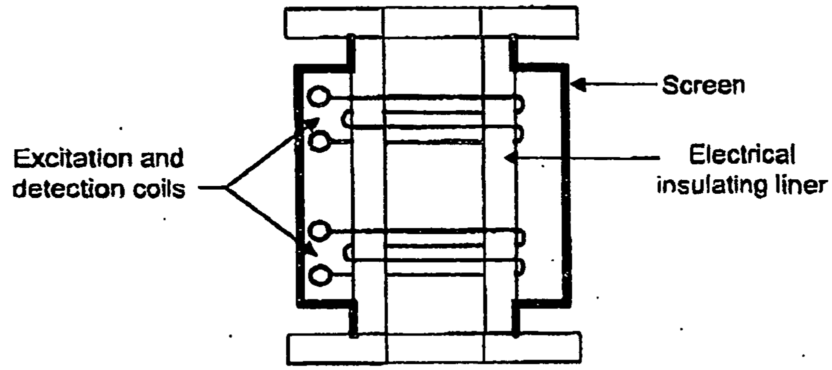
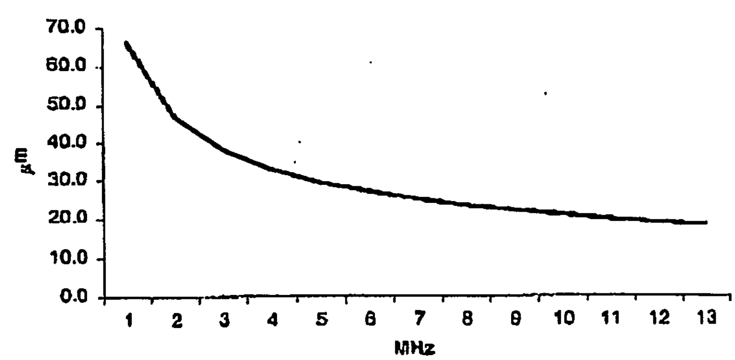

Screen
Excitation and detection coils
Electrical insulating liner

FIG 1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50.0
40.0
30.0
20.0
10.0
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µm
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2
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4
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6
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9
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11
12
13
MHz

FIG 2

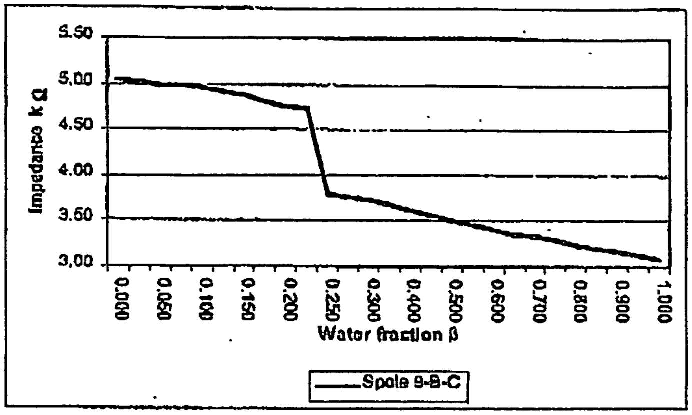
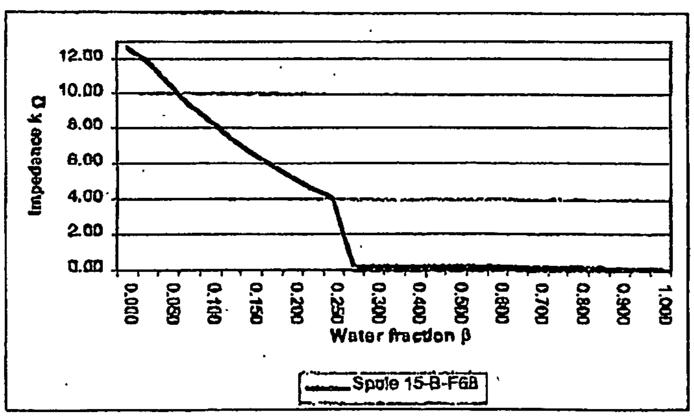

5.50
5.00
4.50
4.00
3.50
3.00
Impedance k Ω
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Water fraction β
Spole 9-B-C

FIG 3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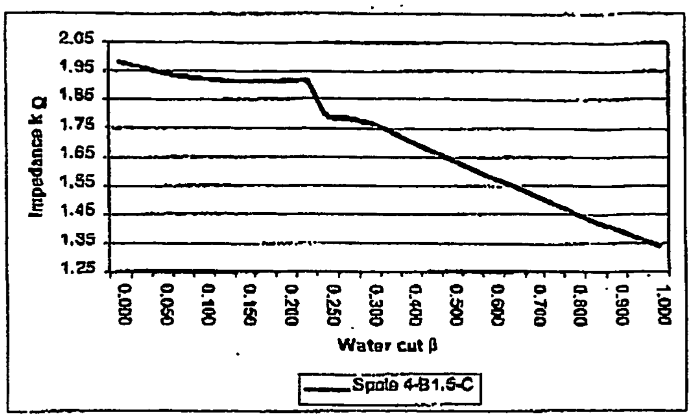
10.00
8.00
6.00
4.00
2.00
0.00
Impedance k Ω
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Water fraction β
Spole 15-B-F6B

FIG 4



2.05
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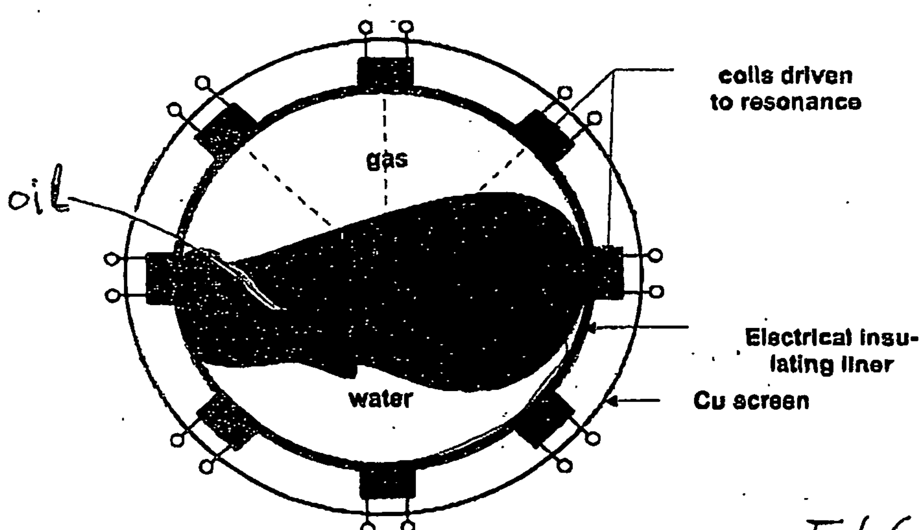
1.85
1.75
1.65
1.55
1.45
1.35
1.25
Impedance k Ω
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.400
0.500
0.600
0.700
0.800
0.900
1.000
Water cut β
Spole 4-B1.5-C

FIG 5



coils driven
to resonance
gas
oil
water
Electrical insu-
lating liner
Cu screen

FIG 6